Application of hurdle rates for Belgian electricity capacity adequacy and flexibility analysis over the period 2024-2034 in a CRM context

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Abstract:

Adequacy and flexibility analysis for the Belgian electricity grid uses a simulation-based approach to evaluate the willingness to invest in new or existing electricity generation capacity. Under this framework, the investment takes place when the expected return exceeds the investment project's hurdle rate, which is set equal to the cost of capital of a reference investor plus a hurdle premium. The latter serves as a cushion to compensate for the deviation of the project's cost of capital from the reference investor's cost of capital based on the predicted project risk under the base scenario, and the model and policy risk related to alternative scenario outcomes. In this paper, we build further on the methodology set out in Boudt (2021, 2022) and we revisit the framework under a market design with a Capacity Remuneration Mechanism (CRM) with reliability options.

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1. Introduction

Will there be sufficient investment in electricity capacity in Belgium to ensure security of supply ("keep the lights on") over the next decade? To answer this question, Elia publishes every two years a detailed ten-year adequacy and flexibility assessment for the Belgian electricity system.[2] Also at European level, similar assessments are done. In particular, the European Network of Transmission System Operators (ENTSO-E) is mandated by European legislation to make a European Resource and Adequacy assessment (ERAA).

The adequacy and flexibility assessment uses simulation methods to determine the extent of capacity needed to maintain security of supply. If a capacity need is identified, an economic viability check should be performed on existing and new capacity for different technologies to see whether they would be viable in the market with the current market design and under the given hypotheses. Within the framework, it is assumed that an investment takes place when the expected return exceeds the project's hurdle rate.

The goal of this report is to present insights on the hurdle rate calibration in a market design with a Capacity Remuneration Mechanism (CRM) with reliability options. Under this design, the capacity providers that are selected in the competitive CRM auction process sell the reliability options and receive a fixed capacity remuneration in return. Whenever the electricity price on the wholesale day-ahead market exceeds a pre-defined level, the so-called strike price, the capacity provider has a payback obligation of the difference between the reference price and the strike price. As a result, revenues for the capacity provider on the energy only market are capped at the strike price, but capacity providers are ensured a fixed and certain capacity remuneration in return. In other words, the capacity providers give up part of their uncertain scarcity rents to receive a certain capacity remuneration in return, reducing the risk of volatile revenues and therefore the risks related to the investment to be made, and reducing the expected energy market revenues at the same time.

[2] See https://www.elia.be/en/electricity-market-and-system/adequacy/adequacy-studies

2. Simulation setup in a market design with CRM

The hurdle rate framework requires to select a reference scenario that drives the probabilistic distribution of returns of the investment.

The context of a market design with CRM changes the base scenario, compared to the scenario used for the hurdle rate calibration in an Energy Only Market (EoM) context in Boudt (2021) and Boudt (2022). The new base scenario is the one of adequacy in which the legal reliability standard would be met, i.e. with reduced average price levels and lower number of price spikes, as compared to the inadequate scenario. This leads to lower expected returns. When investors receive a capacity remuneration, the downside risk is reduced, which leads to lower hurdle rates.

There is still substantial model risk given the uncertainty about the future decisions in the CRM and the risk impact is heterogeneous across technologies.

We start our analysis with a description of the distribution of inframarginal rents under three scenarios: (i) EVA tipping point (inadequate), (ii) adequacy without a CRM contract, and (iii) adequacy with a CRM contract. Boudt (2021) studies in detail the case of inadequacy, as it is the reference scenario to build the hurdle rates in EoM. Boudt (2021) studies the case of adequacy without a CRM contract as an alternative scenario but does not present hurdle rates when this scenario is the reference scenario. Subsection 2.2 proposes hurdle rates for this scenario. The analysis of adequacy with a CRM contract is new and requires also new methodology for the calibration of the hurdle rate. Subsections 2.3 develops this methodology and proposes hurdle rates in this setup.

2.1. Distribution of inframarginal rents

A key input for the simulation analysis is the reference distribution of inframarginal rents per technology. Table 1 describes the three scenarios considered: one inadequate scenario and two adequate ones. In a market design with a CRM (adequate), we need to distinguish between the inframarginal rent distribution of capacities that do not have a CRM contract and those that do have one.

Table 1 Overview of scenarios studies

Acronym	Scenario Label	Description
_inad	Capacity in a market design without CRM (EoM, inadequate)	Economic Viability Assessment (EVA) tipping point scenario at an equilibrium where no additional capacities are economically viable (resulting in an inadequate scenario). Price cap at 3000 EUR/MWh.
_ad	Capacity without a CRM contract in a market design with CRM (adequate)	Adequate scenario (LOLE = 3h). Price cap at 3000 EUR/MWh.
_adCRM	Capacity with a CRM contract in a market design with CRM (adequate)	Adequate scenario (LOLE = 3h). Price cap at 3000 EUR/MWh. Revenues bounded at strike price (assumed to be 300 EUR/MWh).

Table 2 reports the mean and standard deviation of the inframarginal rent distribution for each scenario. Note that the change from inadequate to adequate without CRM contract reduces both the mean inframarginal rents and the standard deviation of the inframarginal rents. The adequate scenario with CRM contract further strengthens this impact[3].

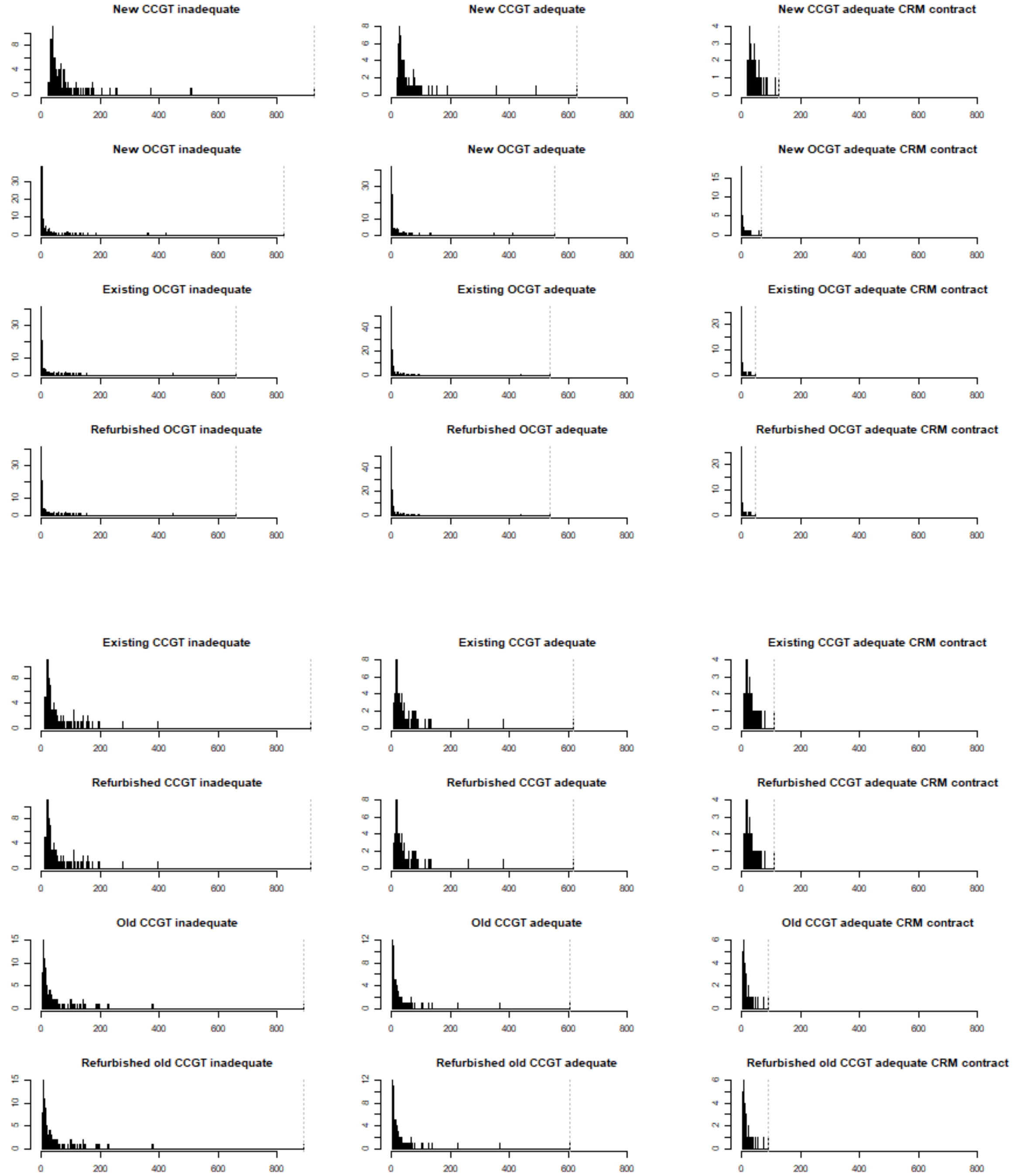
Table 2 Effect of scenario on mean and standard deviation of the distribution of inframarginal rents

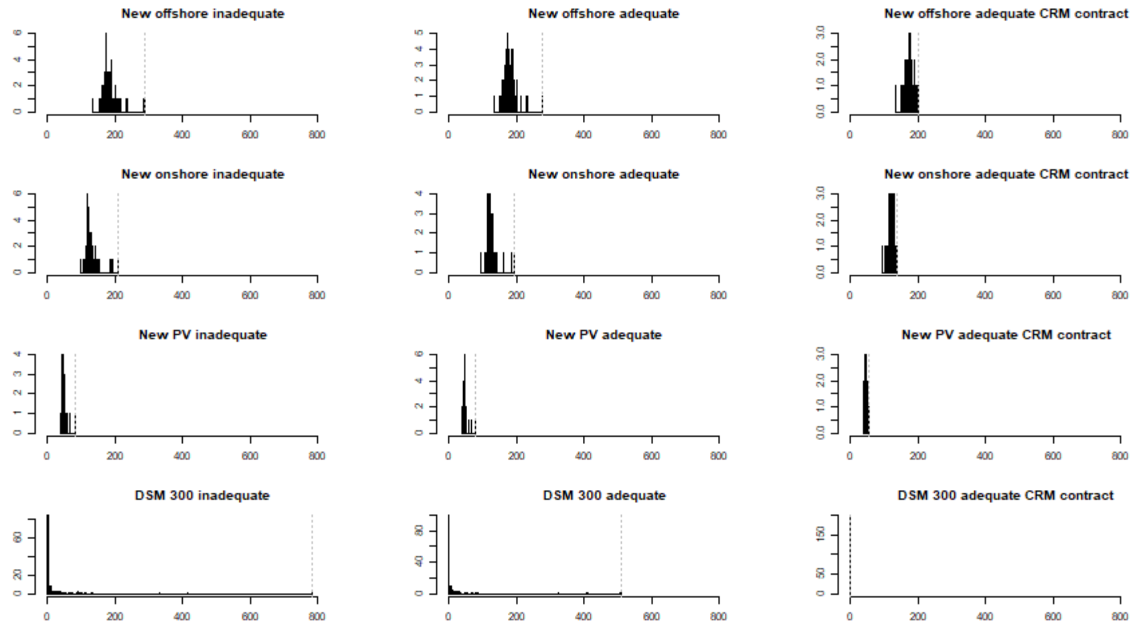
	mean_inad	mean_ad	mean_adCRM	sd_inad	sd_ad	sd_adCRM
New CCGT	67.87	47.76	34.82	82.03	61.51	14.61
New OCGT	27.69	17.02	4.32	75.34	56.47	8.30
Existing OCGT	23.44	14.38	2.86	62.31	51.09	5.61
Refurbished OCGT	23.44	14.38	2.86	62.31	51.09	5.61
Existing CCGT	50.11	32.95	20.94	77.89	55.98	13.12
Refurbished CCGT	50.11	32.95	20.94	77.89	55.98	13.12
Old CCGT	36.10	22.67	10.69	76.45	55.02	11.36
Refurbished old CCGT	36.10	22.67	10.69	76.45	55.02	11.36
New offshore	180.28	175.17	173.01	17.00	14.10	9.72
New onshore	124.96	121.16	119.36	12.26	10.11	6.25
New PV	45.87	44.81	44.42	4.26	3.80	2.48
DSM 300	21.24	13.51	0.00	69.81	52.52	0.00
DSM 500	18.07	11.72	0.00	63.76	47.83	0.00
DSM 1000	13.88	9.24	0.00	50.68	38.20	0.00
DSM 2000	6.77	4.50	0.00	25.27	19.08	0.00
Batteries 2h	13.56	10.25	5.58	11.05	9.17	1.57
Batteries 4h	23.92	18.96	12.19	17.06	13.94	2.64

These changes are primarily driven by a reduction in the number of price spikes under the adequacy scenario and the capping of the revenues at the strike price in the adequate scenario with CRM contract. This leads to less extreme inframarginal rents, as shown below in the histogram of the inframarginal rents.

[3] The result of 0 EUR mean inframarginal rents for demand response capacities (DSM 300, DSM 500, DSM 1000 and DSM 2000) follows from a simplification in the analysis: it is assumed that these DSR capacities are also subject to the strike price of 300 EUR/MWh. Given that all DSM capacities in the dataset have an activation price above the assumed strike price, their inframarginal rents always equal 0 EUR. In reality, such DSR capacities can use an individual declared market price in the Belgian CRM. Also, DSR capacities can earn balancing revenues which are not taken into account in Table 2.

Figure 1 Distribution of inframarginal rents for three scenarios (inadequate, adequate without CRM contract, adequate with CRM contract)





In the histogram, we can see that the technologies with a peak at zero in the inadequacy scenario tend to preserve this peak in the adequate scenario. This suggests that the adequacy scenario presents still considerable downside risk. We quantify this below by presenting the probability of observing a year with zero inframarginal rents. We find that, for those technologies that have a non-zero probability of zero inframarginal rents in a year under the inadequacy scenario, switching to the adequacy scenario increases further this probability.

Table 3 Effect of scenario on probability of observing zero inframarginal rents

	P(IR=0)_inad	P(IR=0)_ad	P(IR=0)_adCRM
New CCGT	0.00	0.00	0.00
New OCGT	0.02	0.03	0.03
Existing OCGT	0.04	0.12	0.12
Refurbished OCGT	0.04	0.12	0.12
Existing CCGT	0.00	0.00	0.00
Refurbished CCGT	0.00	0.00	0.00
Old CCGT	0.00	0.00	0.00
Refurbished old CCGT	0.00	0.00	0.00
New offshore	0.00	0.00	0.00
New onshore	0.00	0.00	0.00
New PV	0.00	0.00	0.00
DSM 300	0.17	0.24	1.00
DSM 500	0.38	0.53	1.00
DSM 1000	0.48	0.57	1.00
DSM 2000	0.52	0.63	1.00
Batteries 2h	0.00	0.00	0.00
Batteries 4h	0.00	0.00	0.00

2.2. Simulation setup for an investment in capacity without having a CRM contract

In a market design with a CRM, the most uncertain investments are the ones that do not participate in the capacity mechanism and only receive inframarginal rents from the energy markets and revenues from ancillary services.[4]

As shown above, compared to the inadequacy scenario, the probability of reaching extreme prices and thus extreme marginal rents is lower. This limits the upside potential leading to lower expected income from inframarginal rents. As shown above, there is still a substantial downside risk.

The adequacy scenario (versus inadequacy) further does not change the considerations about the merit order impact, effect of lifetime, CAPEX and higher costs on the ranking of technologies in terms of hurdle premium (see Boudt, 2021, 2022). As such, to a first approximation, one could use the same

[4] Besides the inframarginal rents from the wholesale electricity markets, some technologies can indeed earn additional market revenues by offering ancillary services.
We note that the exact level of ancillary revenues that a capacity can obtain is highly uncertain. First of all, contracts for ancillary services are short term and do not provide any long-term certainties, similar to the day-ahead market. The volumes that the TSO needs for ancillary services vary every year and the volumes (MW) needed for ancillary services are below the level of total installed capacity in the system. Hence, investors have no guarantee at all to receive such additional revenues.

risk premiums for the investments in capacity without CRM contract in a scenario of adequacy as in a scenario of inadequacy.

Specifically, the real hurdle rate is then given by the WACC of a reference investor (the same for all technologies) and the technology-specific hurdle premium. Denote by k_{tech} the real hurdle rate for a technology tech, then:

$$k_{tech} = WACC^{*} + kpremium_{tech}$$

with the (pre-tax and real) value of the WACC for the reference investor equal to:

$$WACC^{*} = \frac{1+\left[COE^{*} \cdot \frac{1-g^{*}}{1-t} + CoD^{*} \cdot g^{*}\right]}{1+i} - 1.$$

This $WACC^{*}$ is computed using the cost of equity (CoE), cost of debt (CoD), and gearing ratio (g, i.e. percentage of debt-based funding) of the reference investor. In addition the corporate tax rate (t) and expected inflation (i) over the project's investment horizon are needed.

For the cost of equity, we have $CoE^{*} = r_f + \beta \cdot ERP + CRP$, where r_f is the long-term risk-free rate, β is the systematic risk of the reference investor, ERP is the equity risk premium and CRP is the country risk premium.

2.2.1. Calibration of the reference investor WACC for the period 2024-2034

For long-term investments in electricity capacity in Belgium over the period 2024-2034, a reasonable calibration is to set the nominal risk-free rate at 2.1% (as based on the average long term interest rate for Germany in October-December 2022).[5]

Following Damodaran, the country risk premium of Germany in July 2022 is 0% while it is 0.07% for Belgium. The general market equity premium is at 5.94%.[6] Using a set of representative utilities and energy companies, the equity beta for a reference investor is estimated at 0.83.[7] Given these parameters we can compute the nominal cost of equity:

$$CoE^{*} = r_f + \beta^{*} \cdot ERP + CRP = 2.1\% + 0.83 \cdot 5.94\% + 0.07\% = 7.1002\%.$$

The cost of debt and gearing ratio can be estimated by analysing the balance sheet of prospective investors and adjusting for the change in interest rates between the reporting period of the balance sheet and the future period of interest. A reasonable number here is that $CoD^{*} = 5\%$ and a gearing ratio of 44%. Assuming a corporate tax rate of 25% we have that the nominal WACC of the reference investor equals

$$\text{Nominal WACC} = CoE^{*} \cdot \frac{1-g^{*}}{1-t} + CoD^{*} \cdot g^{*} = 7.1002\% \cdot \frac{1-0.44}{1-0.25} + 0.05 \cdot 0.44 = 7.5015\%.$$

[5] See https://www.ecb.europa.eu/stats/financial_markets_and_interest_rates/long_term_interest_rates/html/index.en.html

[6] https://pages.stern.nyu.edu/~adamodar/pc/datasets/ctrypremJuly22.xlsx

[7] The equity beta, the gearing and the cost of debt parameters take into account publicly available data from energy market players in Europe. Detailed calculations are available from the author.

The expected inflation is set to 2.7%.[8] Assuming a corporate tax rate of 25% we have that the real $WACC^*$ equals 4.6753%:

$$WACC^* = \frac{1+\left[CoE^* \cdot \frac{1-g^*}{1-t} + CoD^* \cdot g^*\right]}{1+i} - 1 = \frac{1+\left[7.1002\% \cdot \frac{1-0.44}{1-0.25} + 0.05 \cdot 0.44\right]}{1+2.7\%} - 1 = 4.6753\%.$$

Table 4 Parameters for the calibration of the reference WACC for the period 2024-2034 in case of the adequate scenario without and with CRM contract

	params_ad	params_adCRM
nom_rf	0.0210	0.0210
nom_emr	0.0594	0.0594
country_premium	0.0007	0.0007
corporateBeta	0.8300	0.8300
gearing	0.4400	0.7500
CoD	0.0500	0.0500
taxrate	0.2500	0.2500
inflation	0.0270	0.0270
WACC (nominal)	0.0750	0.0612
WACC (real)	0.0468	0.0333

Note: The reference investor for capacity without a CRM contract has a gearing ratio of 44%. We assume that, in the context of a CRM contract, there is a higher willingness of banks to accept a higher gearing ratio, which we assume to be at 75%.

2.2.2. Hurdle premium calibration for the period 2024-2034

The project WACC equals the reference WACC plus a technology-specific hurdle premium. Under the framework described in Boudt (2021, 2022), we set the minimum nominal hurdle premium to 5%. The corresponding minimum real hurdle premium is $\frac{1+5\%}{1+2.7\%} - 1$ = 2.22% leading to a minimum real hurdle rate of 6.92%. We use also the technology-specific hurdle premiums presented in Boudt (2022) to compensate for the downside risk, policy risk and model risk. For every technology we then have a real hurdle rate (denoted by k_{tech}) and a nominal hurdle rate (denoted by h_{tech}).

[8] See https://www.ecb.europa.eu/stats/ecb_surveys/survey_of_professional_forecasters/html/table_hist_hicp.en.html

Table 5 Real and nominal hurdle rates per technology in the scenario of adequacy without CRM contract

	lifetime	capex	kpremium_ad	k_ad	h_ad
New CCGT	20	600	0.045	0.092	0.121
New OCGT	20	400	0.060	0.107	0.137
Existing OCGT	3	0	0.035	0.082	0.111
Refurbished OCGT	15	80	0.050	0.097	0.126
Existing CCGT	3	0	0.030	0.077	0.106
Refurbished CCGT	15	100	0.040	0.087	0.116
Old CCGT	3	0	0.030	0.077	0.106
Refurbished old CCGT	15	100	0.040	0.087	0.116
New offshore	15	2300	0.022	0.069	0.098
New onshore	15	1000	0.022	0.069	0.098
New PV	15	600	0.022	0.069	0.098
DSM 300	3	0	0.035	0.082	0.111
DSM 500	3	0	0.037	0.084	0.114
DSM 1000	3	0	0.042	0.089	0.119
DSM 2000	3	0	0.042	0.089	0.119
Batteries 2h	15	400	0.030	0.077	0.106
Batteries 4h	15	750	0.030	0.077	0.106

2.3. Simulation setup for capacity with a CRM contract

For capacities with a CRM contract, the hurdle premiums change substantially because of the reduction in revenues uncertainty thanks to the additional source of revenue coming from the CRM contract. Specifically, in a market design with CRM, the projects that receive capacity payments from the CRM combine revenues from two main sources[9]: revenues from the electricity markets (including inframarginal rents and ancillary income services) and from the capacity payments (that aim to cover the missing money) through the CRM framework.

Below we do the analysis for an investor who obtained a CRM contract with a strike price of 300 EUR/MWh for a CRM contract duration of 15 years[10]. In this scenario, the price cap is still set at 3000 EUR/MWh, but revenues are capped at 300 EUR/MWh leading to inframarginal rents bounded at 300 EUR/MWh. The actual rents are thus uncertain, but the uncertainty is smaller compared to a scenario with no cap on revenues.

[9] This is a simplification given that for some technologies, other revenue sources exist (e.g. heat revenues, revenues from green certificates, etc.).
[10] Cf. strike price that was applicable to the Y-4 Auction for Delivery Period 2025-2026.

2.3.1. Variations in uncertainty of revenues for capacities with a CRM contract

The uncertainty for this investor depends also on the proportion of revenues that are derived from missing money payments. Let's differentiate between two extreme scenarios:

1. The CRM contract is signed but the investor expects to receive zero revenues coming from the capacity remuneration. All revenues are fully subject to price risk on the electricity markets. This scenario will define an upper bound on the hurdle rate per technology.
2. The CRM contract is signed and the investor expects that there will be no additional revenues from the electricity markets. It follows that the full investment and FOM costs are considered as "missing money" and covered under the CRM. While the capacity remuneration is guaranteed, there is still model risk in terms of the assumptions regarding the FOM as well as the future evolution of costs (e.g. due to inflation). The situation of expecting to receive exclusively revenues from the CRM payments corresponds to the investment with the lowest hurdle rate. It may still differ across technologies due to for example the investment horizon.

Based on this discussion, it is clear that the hurdle rate for projects that have signed a CRM agreement depends on the value of the capacity payments relative to the total revenues. This is the result of a competitive bidding process, for which we need to model the outcome. The following section builds on the assumption that investors will bid their yearly missing money in the CRM auction as a result of the competitive bidding process.

2.3.2. Effect of variations in uncertainty of revenues on hurdle rate for capacity with a CRM contract

The goal of this subsection is to present an equation of the hurdle rate per technology. We use the following notation:

- We have different technologies that we denote by the underscript *tech*.
- For every technology we have a real hurdle rate (denoted by k_{tech}) and a nominal hurdle rate (denoted by h_{tech}). The two are linked by the expected inflation (denoted by i). Using the Fisher rule, we have that $1 + h_{tech} = (1 + k_{tech})(1 + i)$ and thus $h_{tech} = (1 + k_{tech})(1 + i) - 1$.

Without loss of generality, we can introduce the range of values that are allowed for the real hurdle rate for investing in capacity with a CRM contract. As mentioned above, the lowest hurdle rate is expected when all revenues are capacity remuneration payments, while the highest hurdle rate is when there is zero payment from CRM. Denote the lower bound by $kmin_{tech}(hmin_{tech})$ and the upper bound by $kmax_{tech}$ $(hmax_{tech})$.

We assume a linear relation between the hurdle rate and the proportion of expected risky payments relative to the total amount of payments expected:

$$h_{tech} = hmin_{tech} + (hmax_{tech} - hmin_{tech}) \cdot proprisky_{tech} \quad (1)$$

where

$$proprisky_{tech} = \frac{E[\,InfraRents_{tech} + Ancillary\ Income_{tech}]}{E[\,InfraRents_{tech} + Ancillary\ Income_{tech}] + Capacity\ Remun_{tech}}. \quad (2)$$

By construction we have that when $proprisky_{tech} = 0$, then $h_{tech} = hmin_{tech}$, while if $proprisky_{tech} = 1$, then $h_{tech} = hmax_{tech}$. Alternative increasing functions could be considered such as a logistic function, but the linear specification has the advantage of simplicity and no need to further calibrate additional curvature parameters.

For the expected inframarginal rents and ancillary income, we can rely on a calibration that follows from the scenario assumptions. For the capacity payments (that aim to cover the missing money), we need further model assumptions to ensure that it is aligned with the hurdle rate. Indeed, the higher the hurdle rate, the more capacity payments are required for the investors to be willing to invest. In the next section we present a model for this.

2.3.3. CRM payment equal to missing money

The CRM payments are a consequence of a competitive bidding. The payment is annual and assumed to be the same amount each year. The payment should cover the difference between the costs (including the required rate of return) and expected revenues. Below we describe a model to predict the required CRM payment by the investor. As any model of economic behavior, it is a simplified representation of the CRM payment requirement by an investor. We discuss the impact of model risk in Subsection 2.3.5. We assume that the investor determines the required CRM payment based on a Net Present Value (NPV) analysis of expected net revenues and taking the hurdle rate into account. The NPV analysis assumes that the investor receives the CRM payment for each year over the economic lifetime L of the investment, even when this lifetime exceeds the initial contract duration of the CRM. In Subsection 2.3.5 we discuss how to cover the impact of a shorter contract period in a qualitative way.

Since the CRM payment is fixed, we need to adjust for the impact of expected inflation and therefore use nominal hurdle rates in the analysis. In terms of notation, the model description starts by specifying the yearly net cash flow corresponding to the technology's FOM in excess of the expected revenues from inframarginal rents and ancillary income.

Denote by $Z_{tech} = FOM_{tech} - E[InfraRents_{tech}] - E[Ancillary\ Income_{tech}]$ the yearly variable costs in excess of expected revenues from inframarginal rents and ancillary income, expressed in euro value as of today. To do the NPV analysis over the economic lifetime L, we make the behavioural assumption that in the bidding process the investor will take into account inflation. As such, the amount is expected to increase yearly with inflation such that its expected value in years $1,2,..,L$ equals $Z_{tech}(1+i)$, $Z_{tech}(1+i)^2$ and $Z_{tech}(1+i)^L$.

Denote by $MM_{tech,1}$, $MM_{tech,2}$,..., $MM_{tech,L}$ the missing money payment in years $1,2,..,L$. We allow them first to be variable and will in a next step convert them into a fixed equivalent amount.

The Net Present Value of all expected cashflows associated to the investment in capacity equals:

$$NPV_{tech} = -CAPEX_{tech} + \frac{MM_{tech,1} - Z_{tech}(1+i)}{(1+h_{tech})} + \frac{MM_{tech,2} - Z_{tech}(1+i)^2}{(1+h_{tech})^2} + \cdots + \frac{MM_{tech,L} - Z_{tech}(1+i)^L}{(1+h_{tech})^L}. \quad (3)$$

In order to express everything on the same denominator, we can rewrite the total CAPEX as the sum of annualized CAPEX values:

$$CAPEX_{tech} = \frac{Ann.CAPEX_{tech}}{(1+h_{tech})} + \frac{Ann.CAPEX_{tech}}{(1+h_{tech})^2} + \cdots + \frac{Ann.CAPEX_{tech}}{(1+h_{tech})^L}, \quad (4)$$

which holds when

$$Ann.CAPEX_{tech} = CAPEX_{tech} \cdot \left(\frac{h_{tech}}{1 - \frac{1}{(1+h_{tech})^L}} \right). \quad (5)$$

The Net Present Value of all expected cashflows associated to the investment in capacity equals:

$$NPV_{tech} = \frac{MM_{tech,1} - Ann.CAPEX_{tech} - Z_{tech}(1+i)}{(1+h_{tech})} + \frac{MM_{tech,2} - Ann.CAPEX_{tech} - Z_{tech}(1+i)^2}{(1+h_{tech})^2} + \cdots + \frac{MM_{tech,L} - Ann.CAPEX_{tech} - Z_{tech}(1+i)^L}{(1+h_{tech})^L}. \quad (6)$$

A sufficient condition for the NPV to be positive is the condition that in each year the revenues need to cover the costs. This is satisfied when the missing money in each year y equals:

$$MM_{tech,y} = \max\{Ann.CAPEX_{tech} + Z_{tech}(1+i)^y, 0\}. \quad (7)$$

This equation provides insights on the impact of expected inflation on the missing money calculation. An increase in expected inflation increases the Missing Money for technologies for which the FOM is higher than the expected annual revenues ($Z_{tech} = FOM_{tech} - E[InfraRents_{tech}] - E[Ancillary\ Income_{tech}] > 0$) and vice versa for the technologies that have expected annual revenues exceeding the FOM costs.

The capacity payments $Capacity\ Remun_{tech}$ under the CRM are constant. In order to obtain the equivalent annual constant amount $Capacity\ Remun_{tech}$ one then seeks for the value of $Capacity\ Remun_{tech}$ for which the equality holds between the net present value of the annual fixed amount and the net present value of the time-varying amounts:

$$\frac{Capacity\ Remun_{tech}}{(1+h_{tech})} + \cdots + \frac{Capacity\ Remun_{tech}}{(1+h_{tech})^L} = \frac{MM_{tech,1}}{(1+h_{tech})} + \cdots + \frac{MM_{tech,L}}{(1+h_{tech})^L}, \quad (8)$$

which leads to:

$$Capacity\ Remun_{tech} = \left(\frac{MM_{tech,1}}{(1+h_{tech})} + \cdots + \frac{MM_{tech,L}}{(1+h_{tech})^L}\right) \cdot \left(\frac{h_{tech}}{1 - \frac{1}{(1+h_{tech})^L}}\right). \quad (9)$$

2.3.4. Iterative procedure to determine hurdle rate and MM

The nominal hurdle rate should reflect the investor's uncertainty about the total revenues. Since the capacity remuneration revenues are quasi guaranteed, we have that the higher is the contribution of MM to the total revenues, the lower should be the hurdle rate.
The value of MM_{tech} depends on h_{tech} and vice versa. We thus iterate until convergence to obtain h_{tech} and MM_{tech} jointly.

The algorithm is then as follows:

1. Specify for each technology the values of L, $hmin_{tech}$, $hmax_{tech}$, FOM_{tech}, $CAPEX_{tech}$, $E[InfraRents_{tech}]$, $E[Ancillary\ Income_{tech}]$
2. Initialize h_{tech} at ($hmin_{tech}$+$hmax_{tech}$)/2
3. Compute $Ann.CAPEX_{tech}$ using equation (5)
4. Compute $Capacity\ Remun_{tech}$ using equation (7) and (9)
5. Update h_{tech}
6. Iterate step 3-5 till convergence is reached (usually within 2-3 iterations).

2.3.5. Additional comments

The approach also applies to capacity without capex who are eligible to participate to the CRM. In that case, the algorithm is the same with $Ann.CAPEX_{tech} = 0$.

The approach presented above makes a number of model assumptions. It is therefore worth mentioning that there is an important level of model risk in terms of simulating the missing money itself as this estimation depends on the expected inframarginal rents (which are subject to model and policy risk) and ancillary income.

One assumption that is clearly violated for the capacities with investment in CAPEX that have a longer economic investment than the CRM contract duration is that the capacity remuneration is received in each year of the investment period equal to the lifetime L of the investment. In practice, the CRM contract duration is often shorter than the economic lifetime and the CRM payment is thus not guaranteed for the years following the initial CRM contract duration. This assumption on the lifetime affects the yearly missing money calculation. As can be seen in equation (7), by using a longer lifetime than the CRM contract duration, we underestimate the annualized CAPEX calculation used by the investor to simulate its bid price, and thus overestimate the proportion of risky income and the hurdle rate. This overestimation could be considered as a compensation for the higher model risk in case of longer lifetime.

A further important element that we do not take into account is the timing of the CRM auctions. There are both Y-4 Auctions & Y-1 Auctions in the Belgian CRM (4 years before the start of the delivery period and 1 year before the start of the delivery period). The model risk is higher for the Y-4 Auctions than for the Y-1 Auctions given that the prediction horizon is longer, implying that a higher hurdle rate is applicable if the capacity contract is obtained in a bidding 4 years ahead of the delivery period.

Finally, in our model for investor behaviour, we have assumed that the investor uses the same benchmark for expected inflation as the one used to compute real hurdle rates from nominal ones. In practice, the inflation may be more specific to the inflation rate applicable to the cost and revenue structure of each technology[11].

2.3.6. Illustration - Initialization

The above sections have described the algorithm to obtain the hurdle rate and capacity remuneration for replicating the investment in capacity with a CRM contract. We now apply it using the market parameters of Table 4 to obtain values for the hurdle rate of the various technologies under this scenario.

We set $hmin_{tech}$ and $hmax_{tech}$ as the hurdle rate of a reference investor plus a premium. As explained more in detail in section 2.2 for $hmax_{tech}$ we take the hurdle rates of the investor without a CRM contract in the scenario of inadequacy as an approximation. This is a theoretical value, as, when the investor will not have CRM payments, then the rational choice is to have no CRM contract and thus avoid the obligations under such a contract.

To obtain $hmin_{tech}$ we include the possibility of increasing the gearing ratio in case of substantial capacity payments and set it to 75%. This increased gearing ratio reflects the expected increased

[11] For example, for specific equipment, a PPI (Producer Price Index) is more relevant to estimate cost evolutions.

willingness of financial institutions to provide debt financing in case the full investment is covered by fixed capacity remuneration. This then leads to the following lower bound on the hurdle rates:

$$hmin_{tech} = [\, CoE^* \cdot \frac{1-g^*}{1-t} + CoD^* \cdot g^*] = 6.1167\%$$

We further assume that the nominal hurdle premiums have a minimum value of 0% in the adequacy scenario with CRM contract (versus 5% otherwise). To preserve the heterogeneity in risk across technologies, we shift all nominal premiums reported by Boudt (2022) by 5 percentage points. Specifically, this means subtracting 5 percentage points (nominal) from all (nominal) premiums.

The expected revenues for ancillary income are set to 0, except for batteries (expected value at 12 EUR/kW/y), OCGT (expect value of 14 EUR/kW/y) and for DSM (expected value of 19 EUR/kW/y).[12]

2.3.7. Illustration - Results

The resulting nominal hurdle rates are shown in the first column of the table below. The second column indicates the percentage of risky outcomes. The higher this percentage, the closer the nominal hurdle rate is to the maximum hurdle rate, which is the one for capacity in the adequate scenario without CRM contract. The last column is the real hurdle rate. The nominal and the real hurdle rate are linked by the Fisher equation: $h_{tech} = (1 + k_{tech})(1 + i) - 1$, where i is the expected inflation.

Table 6 Nominal (h) and real (k) hurdle rates per technology in the scenario of adequacy with CRM contract

	prop.risky	hmin	hmax=h_ad	k_adCRM	h_adCRM
New CCGT	0.377	0.084	0.121	0.069	0.098
New OCGT	0.260	0.100	0.137	0.080	0.109
Existing OCGT	0.836	0.074	0.111	0.076	0.105
Refurbished OCGT	0.307	0.090	0.126	0.072	0.101
Existing CCGT	0.687	0.069	0.106	0.066	0.094
Refurbished CCGT	0.469	0.079	0.116	0.068	0.097
Old CCGT	0.344	0.069	0.106	0.053	0.082
Refurbished old CCGT	0.232	0.079	0.116	0.059	0.088
New offshore	0.523	0.061	0.098	0.052	0.080
New onshore	0.748	0.061	0.098	0.060	0.089
New PV	0.489	0.061	0.098	0.051	0.079
DSM 300	0.368	0.074	0.111	0.059	0.088
DSM 500	0.368	0.077	0.114	0.062	0.090
DSM 1000	0.368	0.082	0.119	0.067	0.095
DSM 2000	0.368	0.082	0.119	0.067	0.095
Batteries 2h	0.288	0.069	0.106	0.051	0.080
Batteries 4h	0.243	0.069	0.106	0.050	0.078

[12] See CRM calibration report.

The nominal hurdle rates determine the annualized CAPEX and Capacity Remuneration values. They are shown in the table below. Remuneration is higher when the hurdle rate is higher and, in case of a CAPEX investment, the lifetime is shorter. Note also that, because of the NPV break-even condition, the sum of the capacity remuneration, mean inframarginal rent and ancillary income is similar to the sum of the annualized CAPEX and FOM. The difference between both is due to the inflation dynamics that affect all revenue and cost components, except for the capacity remuneration and annualized CAPEX which are assumed to be constant (see Equation (7)).

Table 7 Overview of revenues and costs (EUR/kW/y) in the scenario of adequacy with CRM contract[13]

	Capac.Remun_adCRM	mean.rents	ancil	ann.capex_adCRM	fom
New CCGT	57.529	34.818	0	69.658	25
New OCGT	52.090	4.319	14	50.029	20
Existing OCGT	3.302	2.864	14	0.000	20
Refurbished OCGT	38.074	2.864	14	10.567	40
Existing CCGT	9.544	20.939	0	0.000	30
Refurbished CCGT	23.681	20.939	0	12.889	30
Old CCGT	20.347	10.687	0	0.000	30
Refurbished old CCGT	35.335	10.687	0	12.245	30
New offshore	157.855	173.012	0	269.410	80
New onshore	40.116	119.358	0	123.007	50
New PV	46.445	44.420	0	69.749	25
DSM 300	32.656	0.000	19	0.000	50
DSM 500	32.654	0.000	19	0.000	50
DSM 1000	32.652	0.000	19	0.000	50
DSM 2000	32.652	0.000	19	0.000	50
Batteries 2h	43.520	5.581	12	46.616	15
Batteries 4h	75.492	12.186	12	86.521	15

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[13] Please note that there is no direct relation to the CRM auction parameters.